Solar Flares

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A solar flare is an explosive event in a magnetic region of the solar atmosphere. Apparently, stored magnetic energy is suddenly released low in the corona, driving bulk mass motion, heating plasma, and accelerating electrons and ions to hard x-ray energies and beyond. In particular, the magnitude and energy spectrum of the resulting burst of hard x rays often indicate that:

- Much of the released energy goes to the energization of electrons to tens of kilovolts;
- The number of these electrons in the burst is comparable to the total number of electrons in the preflare coronal volume of the flaring magnetic field; and
- The total energy channeled into these electrons is a sizeable fraction of the total preflare magnetic energy in the flare volume.

The observed hard x-ray emission from flares thus confronts solar astrophysicists with what is known as the electron bulk energization problem: How does the flare energy-release process manage to be so efficient in energizing electrons to hard x-ray energies? It is this difficulty that makes the plasma energization in solar flares one of the fundamental problems of plasma astrophysics.

An enduring central idea in flare physics is that the conversion of magnetic energy into plasma particle energy is accomplished through reconnection of the magnetic field. Under this precept, the question becomes: How can reconnection provide the required electron bulk energization? A few years ago, MSFC solar astrophysicists pointed out that the main function of the reconnection could be to generate MHD turbulence that, in turn, bulk-energizes the electrons as it cascades to small scales.[1] They reasoned that the MHD turbulence expected in strong flares would be intense enough and voluminous enough to provide the electrons for the hard x-ray emission. The question then became: How is the energy in this MHD turbulence transferred to the electrons? In answer to this question, LaRosa, Moore, and Shore[2] proposed that the electrons are bulk-energized in the turbulence by Fermi acceleration at sufficiently small scales in the cascade. These authors also pointed out that for this to be a viable mechanism for the electron energization, the rate of proton energization by the same turbulence cannot exceed the rate of electron energization. Whether the protons could block the Fermi-acceleration energization of the electrons remained an open question.

During the past year, in a collaboration between solar astrophysicists from Kennesaw State College in Marietta, GA, MSFC, University of Alabama in Huntsville, and Indiana University at South Bend,[3] it has been shown that the protons pose no threat to the electron energization by Fermi acceleration. The energization rate for the electrons was derived from first principles, starting from the elements of the wave-particle interactions that yield the Fermi acceleration in MHD turbulence (fig. 170). The energization rate of the protons was derived in the same way. For typical magnetic field strengths and typical densities and temperatures of the plasma entering the turbulence in flares, the protons have initial thermal speeds much slower than the Alfven speed in the turbulence whereas the electrons have initial thermal speeds much faster than the Alfven speed. This difference between the protons and the electrons results in the proton energization rate being entirely negligible compared to that of the electrons. In this way, electron Fermi-acceleration dissipation of MHD turbulence is now established as a strong candidate mechanism for the electron bulk energization in solar flares, and a new front has been opened for attacking the problem of plasma energization in solar flares.

[1]LaRosa, T.N.; Moore, R.L.: "A Mechanism for Bulk Energization in the Impulsive Phase of Solar Flares." *Astrophysical Journal*, 418, 912, 1993.

[2]LaRosa, T.N.; Moore, R.L.; Shore, S.N.: "A New Path for the Electron Energization in Solar Flares: Fermi Acceleration by MHD Turbulence in Reconnection Outflows." *Astrophysical Journal*, 425, 856, 1994.

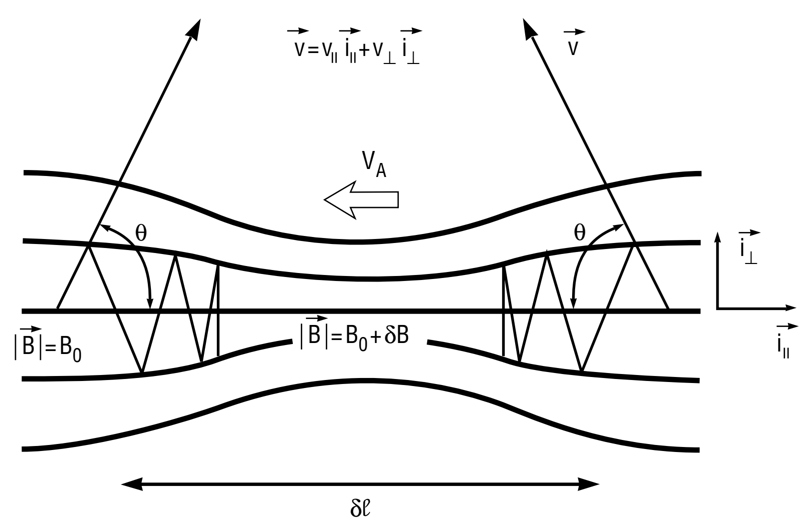

Figure 170.—Elements of the wave-particle interactions in the Fermi acceleration of charged particles in MHD turbulence.

[3]LaRosa, T.N.; Moore, R.L.; Miller, J.A.; Shore, S.N.: “New Promise for Electron Bulk Energization in Solar Flares: Preferential Fermi Acceleration of Electrons Over Protons in Reconnection-Driven MHD Turbulence.” *Astrophysical Journal*, 1996, in press.

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Biographical Sketch: Dr. Ronald L. Moore is an internationally recognized solar scientist. He received his Ph.D. from Stanford University in 1972, was a Research Fellow with the Caltech Solar Astronomy group (1972 through 1980), and joined the MSFC Solar Physics branch in 1981. There, he developed and continues to lead a research program on observed solar magnetic fields and their effects in the solar atmosphere. Moore has published over 100 papers on his solar research in refereed journals, conference proceedings, books, and encyclopedias.